

Description

HILL HOLDING BRAKE SYSTEM FOR HYBRID ELECTRIC VEHICLES

BACKGROUND OF INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates generally to a braking system for a hybrid electric vehicle and, more particularly, to a hill holding brake system for a hybrid electric vehicle.

[0003] 2. Background Art

[0004] A conventional wheeled automotive vehicle includes an internal combustion engine powered by fossil fuels. The desire to reduce emissions and consumption of fossil fuels in an internal combustion engine vehicle is well established.

[0005] An electric vehicle comprises a battery and an electrical generator motor powerplant system to provide torque to a set of wheels. However, electric vehicles have limited range, limited power capabilities, and require a substan-

tial amount of time to recharge the battery. Additionally, electric vehicles require the development of an extensive infrastructure to recharge the battery and service the electric vehicles.

[0006] A hybrid electric vehicle includes a conventional internal combustion engine powertrain and an electrical generator motor powerplant. Hybrid electric vehicles reduce emissions and consumption of fossil fuels. Hybrid electric vehicles address the limitations of the electric vehicle relating to battery life, vehicle range, vehicle performance, and vehicle infrastructure development requirements.

[0007] Hybrid electric vehicles can have many different configurations. A limited storage requirement hybrid electric vehicle is one configuration having an internal combustion engine, providing tractive power to the wheels, in combination with an integrated starter generator motor powerplant, providing a small amount of tractive torque to the wheels. The integrated starter generator motor powerplant tractive torque is provided mainly as a boost. The integrated starter generator motor starts the internal combustion engine and charges the battery.

[0008] Vehicle operators prefer hybrid electric vehicles that have braking and acceleration characteristics that are similar to

a conventional internal combustion engine vehicle with an automatic transmission. Holding a vehicle on a hill when an operator's foot is taken off of the brake pedal, called hill holding, is a characteristic desired by vehicle operators. Hill holding in a conventional vehicle occurs when the vehicle is on a hill, the brake pedal and accelerator pedal are not actuated, and the automatic transmission is engaged. The vehicle powertrain delivers enough torque at idle from the internal combustion engine through the transmission to the wheels to hold the vehicle on a hill. The internal combustion engine in a hybrid electric vehicles wastes fuel and produces undesirable emissions to hold the vehicle on a hill because the internal combustion engine must continue to operate while the vehicle is stopped.

[0009] The integrated starter generator motor in a hybrid electric vehicle is capable of delivering enough torque to hill hold. However, the use of the integrated starter generator motor in a hybrid electric vehicle wastes battery power and requires additional cooling during hill holding conditions.

[0010] U.S. Patent No. 6,321,144 to Crombez, for example, discloses a method and system for preventing roll back in an electric vehicle and a hybrid electric vehicle. The rotary

electric traction motor disclosed in Crombez is capable of bi-directional operation and is not directly connected to the internal combustion engine.

[0011] The present invention is directed to providing a robust hill holding system that reduces emissions, increases battery range, and reduces fuel consumption in a hybrid electric vehicle with an integrated starter generator motor.

SUMMARY OF INVENTION

[0012] The present invention relates to a hill holding control method and system for a hybrid vehicle having an internal combustion engine, an integrated starter generator motor, and a electro-hydraulic brake system that provides hydraulic brake torque during a hill holding condition. The present invention improves the operating efficiency and driveability of the hybrid electric vehicle.

[0013] According to one aspect of the invention, a hybrid electric vehicle is provided that includes an internal combustion engine that rotates in a single direction and is connected to an integrated starter generator motor. The integrated starter generator motor is provided for starting the internal combustion engine. The internal combustion engine and the integrated starter generator motor may selectively drive a set of wheels and provide brake torque at each

driven wheel. A vehicle operator can selectively actuate the electro-hydraulic brake system. An electronic brake control system also controls the electro-hydraulic brake system and controls the level of electro-hydraulic brake torque applied to the wheels by the electro-hydraulic brake system. The electronic brake control system actuates the electro-hydraulic brake to hold the vehicle on a hill instead of using engine compression braking torque or integrated starter generator motor braking torque. A powertrain control module turns off the internal combustion engine while the electro-hydraulic brakes are applied during hill holding conditions.

[0014] When a vehicle operator requests acceleration during the hill holding condition, the electronic brake control system reduces electro-hydraulic brake torque at the wheels and the powertrain control module turns on the internal combustion engine. A vehicle transmission is engaged for seamless acceleration following the hill holding brake application.

[0015] Another aspect of the invention relates to the method of holding a hybrid electric vehicle on a hill. A vehicle roll-back state, a vehicle brake pedal actuation measurement, a powertrain pedal actuation measurement, and an inter-

nal combustion engine running state are monitored by the powertrain control module to determine if the hybrid electric vehicle is in a hill holding condition. In a hill holding condition the electronic brake controller actuates the electro-hydraulic brakes and the powertrain control module turns off the internal combustion engine.

[0016] There are numerous benefits accruing to the method and system of the present invention. For example, the method and system:

[0017] 1) improves the operating efficiency of the hybrid electric vehicle by not using the integrated starter generator motor to provide this function and eliminates the need for additional cooling for the integrated starter generator motor;

[0018] 2) improves the drive-ability of the hybrid electric vehicle;

[0019] 3) is capable of holding the hybrid electric vehicle on a hill of greater grade than present transmissions;

[0020] 4) allows a manual transmission vehicle to emulate the hill holding function of a automatic transmission vehicle;

[0021] 5) allows automatic transmissions a more efficient method of hill holding since the clutch pressure does not have to be maintained to provide hill holding; and

[0022] 6) allows hill holding to be performed more efficiently

than present day transmission hill holding systems by not using the transmission to provide this function saving energy by not keeping the clutch pressure on and eliminating the need for additional cooling for the transmission.

[0023] These and other aspects of the invention will be apparent to one of ordinary skill in the art in view of the attached drawings and following detailed description of the preferred embodiment.

BRIEF DESCRIPTION OF DRAWINGS

[0024] Figure 1 is a schematic diagram illustrating a preferred hybrid electric vehicle configuration on which the method of the present invention can be implemented;

[0025] Figure 2 is a schematic diagram illustrating a representative torque controller for the hybrid electric vehicle's dual powerplants;

[0026] Figure 3 is a table of hybrid electric vehicle conditions which dictate hill holding strategies;

[0027] Figure 4 is a flowchart of vehicle transition when the engine is on and the operator desires to creep the vehicle forward;

[0028] Figure 5 is a flowchart of vehicle transition when the engine is off and the operator desires to creep the vehicle forward;

- [0029] Figure 6 is a flowchart of vehicle transition for when the engine is off;
- [0030] Figure 7 is a flowchart of vehicle transition for when the engine is on;
- [0031] Figure 8 is a flowchart of vehicle transition for when the engine is on with no electro-hydraulic brakes and the operator desires to creep the vehicle forward;
- [0032] Figure 9 is a flowchart of vehicle transition for when the engine is off with no electro-hydraulic brakes and the operator desires to creep the vehicle forward;
- [0033] Figure 10 is a flowchart of vehicle transition for when the engine is off with no electro-hydraulic brakes; and
- [0034] Figure 11 is a flowchart of vehicle transition for when the engine is on with no electro-hydraulic brakes.

DETAILED DESCRIPTION

- [0035] Referring now to the drawings figures, there is illustrated in Figure 1 a representative configuration of a hybrid electric vehicle 10 having a internal combustion engine 12 coupled to an integrated starter generator motor 14. The two powerplants are coupled by a clutch 16 to a transmission 18, and a differential 20 to provide torque to a set of vehicle wheels 22. A powertrain control module 24 controls the operating parameters of the internal combustion

engine 12 and the integrated starter generator motor 14. An electronic brake control system 26 controls a set of electro-hydraulic brakes 28. Both controllers are shown as logical units, and can be embodied in one or more separate controller or computer-controlled devices. A vehicle communication data network 30 enables communications between the hybrid electric vehicle components, the electronic brake controller 26 and the powertrain control module 24 at suitable update rates.

[0036] The powertrain control module 24 provides adaptive filtering that activates when the clutch 16 is engaged as the vehicle accelerates from a hill holding condition. The adaptive filtering could be continuously variable or could be provided by a sequence of individual filters.

[0037] Referring now to Figure 2, a diagram of the hybrid electric vehicle torque control system is provided. The system coordinates the powertrain control module 24 with the electronic brake controller 26 to provide hill holding in the hybrid electric vehicle.

[0038] Inputs to the powertrain control module 24 include a gear selector switch 42 that provides the powertrain control module 24 with information relating to the position of the gear selector switch 42. A powertrain torque sensor pro-

vides information relating to the amount of torque delivered by the powertrain 44 to the powertrain control module 24. An accelerator pedal sensor 46 provides the powertrain control module 24 with information corresponding to the position of an accelerator pedal. A vehicle speed sensor 48 provides a value corresponding to the speed of the vehicle to the powertrain control module 24. Values corresponding to a torque limit of the powertrain are obtained at 50 from a lookup tables and provided to the powertrain control module 24.

[0039] Inputs to the powertrain control module 24 from the electronic brake control system 26 include a master cylinder pressure 52 measured by a master cylinder pressure sensor. The electronic brake control system 26 sends a torque modification request at 54 to the powertrain control module 24.

[0040] Inputs to the electronic brake control system 26 from the powertrain control module 24 include the powertrain negative torque limit from a powertrain torque sensor at 56. The powertrain control module 24 provides information from an accelerator position sensor at 58 to the electronic brake controller 26. The vehicle speed sensors 48 and the gear selector switch 42 are analyzed by the powertrain

control module to provide a vehicle direction at 60. The powertrain control module 24 provides the electronic brake controller 26 with data representative of the powertrain torque request at 62, the torque delivered at 64, the final torque request at 66, and the engine on/off state 68. The powertrain control module, using inputs from the gear selector switch 42 and vehicle speed 48, provides the electronic brake controller 26 with the PRDNE direction 70.

[0041] Inputs to the electronic brake controller 26 also include the wheel speed data at 72 from the wheel speed sensors. Brake pedal position sensors provide information relating to a brake pedal request at 74. Brake pressure sensors provide an input for brake pressures at 76.

[0042] The electronic brake controller 26 provides a brake pressure required output at 78 that controls the electro-hydraulic brakes 28 of the vehicle.

[0043] The data inputs and outputs of the powertrain control module 24 and the electronic brake controller 26 process in a vehicle level algorithm and a brake algorithm. The hybrid electric vehicle using the vehicle level algorithm and brake algorithm provides electro-hydraulic brake torque reduction by the electronic brake control system during

driver commanded vehicle acceleration from a vehicle stopped on a hill.

[0044] When the vehicle begins to accelerate under normal driving conditions, the vehicle algorithm reduces the electro-hydraulic brake torque using an adaptive filter that allows the powertrain system to start and provide the traction torque at the same rate. The adaptive filtering can be continuously variable or a sequence of individual filters. The different filters and control logic are determined by vehicle conditions, including environmental conditions, and conditions of vehicle components such as: the clutch, the transmission, the brakes, the engine, the motor, and the battery. Clutch filters may be dependent upon the clutch status, clutch wear, clutch temperature, clutch pressure, and clutch input and output speeds. Transmission filters may be dependent upon transmission current gear, transmission next gear, and transmission configuration. Brake filters may be dependent upon the driver brake pedal command, brake system fault conditions, brake fade/temperature conditions, and the ABS status. Engine and motor filters may be dependent upon master cylinder pressure, throttle angle, engine friction, engine speed, motor speed, motor efficiency, engine brake torque, en-

gine emissions and engine fuel rate. Other miscellaneous filters and control logic may include such factors as the battery state of charge, energy storage device fault conditions, wheel slip conditions, driveline resonance and road surface conditions.

[0045] When the acceleration is complete and the vehicle engages the clutch, the vehicle algorithm decreases the powertrain negative torque limit 62 with an adaptive filter such that the electro-hydraulic brake torque goes off at the same rate and the traction torque is increased. This method of control provides optimal drive-ability and energy savings allowing a seamless handoff between the electro-hydraulic brake torque and the powertrain torque.

[0046] Referring now to Figure 3, a table 90 of hybrid electric vehicle conditions that dictate the hill holding strategy is provided.

[0047] The powertrain control module compares the vehicle speed 48 from the wheel speed sensor with a calibratable vehicle creep speed in column 92. The vehicle creep speed is typically set at 6 miles per hour on a zero percent grade. The application of both the brake pedal and the accelerator pedal determines the existence of a two footer condition. During a two footer condition the vehicle can

be on a grade in a forward or a reverse gear, the vehicle operator actuates both the accelerator pedal for a accelerator torque request and the brake pedal for a brake torque request, and the magnitude of the brake torque request is greater than the accelerator torque request.

[0048] The results of the vehicle rollback determination is displayed in column 94. Vehicle rollback occurs when the driver releases both the accelerator and brake pedals with the vehicle at a rest condition on a grade, while the vehicle is in a forward gear 82 and starts rolling backwards, or when the vehicle is in a reverse gear 82 and starts rolling forward. Column 96 displays the results of electronic brake controller comparison of the brake pedal actuation received by a brake pedal sensor with a calibratable predetermined force X, measured in pounds per square inch. Column 98 displays the powertrain control module comparison of an accelerator pedal actuation, measured by an accelerator pedal sensor, with a calibratable predetermined percentage value Z. Column 100 displays the internal combustion engine's running state from an engine sensor.

[0049] Rows 102 and 134 result in the vehicle in a two footer condition with the engine on and the electro-hydraulic

brakes applying at grade hold torque. The electro-hydraulic brakes applies at the wheel cylinders and is mechanically summed with the total torque request, which is applied additionally. The hill holding strategy maintains electro-hydraulic brakes at the grade hold torque amount, for example, the amount of torque needed to hold the vehicle on approximately 3% grade. The hill holding strategy calculates the total torque request by summing the accelerator pedal torque request and brake pedal torque request.

[0050] When the total torque request is greater than zero, the accelerator pedal torque request at the total torque request amount is added if the magnitude of total torque request is greater than the magnitude of grade hold torque. The hill holding strategy proceeds to the Figure 4 flowchart of the vehicle transition when the engine is on and operator desires to creep vehicle forward.

[0051] When the total torque request is less than zero, additional vehicle friction brake torque is applied as follows.

[0052] If the magnitude of brake pedal torque request is greater than the magnitude of grade hold torque, then the brake torque request applies at the brake pedal torque request minus the grade hold torque.

- [0053] If the magnitude of brake pedal torque request is less than the magnitude of grade hold torque, then no additional friction brake torque is applied and the hill holding strategy proceeds to the Figure 7 flowchart of the transition for when the engine is on.
- [0054] If total torque request equals zero, then the hill holding strategy proceeds to the Figure 7 flowchart of the transition for when the engine is on.
- [0055] Rows 104 and 136 result in the vehicle in a two footer condition with the engine off and the electro-hydraulic brakes applying at grade hold torque. The hill holding strategy continues to apply electro-hydraulic brakes at the grade hold torque amount and adds total torque request as follows.
- [0056] When the total torque request is greater than zero, the vehicle acceleration pedal at total torque request amount is added if the magnitude of total torque request is greater than the magnitude of grade hold torque. The hill holding strategy proceeds to the Figure 5 flowchart of vehicle transition when the engine is off and the operator desires to creep the vehicle forward.
- [0057] When the total torque request is less than zero, the vehicle brake torque is added as follows.

- [0058] If the magnitude of the brake pedal torque request is greater than magnitude of grade hold torque, brake pedal torque request applies at brake pedal torque request minus the grade hold torque.
- [0059] If the magnitude of the brake pedal torque request is less than the magnitude of grade hold torque, no additional friction brake torque is applied. The hill holding strategy proceeds to the Figure 6 flowchart of the vehicle transition for when the engine is off.
- [0060] If the total torque request equals zero, the hill holding strategy proceeds to the Figure 6 flowchart of the transition for when the engine is off.
- [0061] Rows 106 and 138 result in the engine on with a brake pedal torque request, and the electro-hydraulic brakes applying at grade hold torque. Additional brake pedal torque request is added as follows.
- [0062] When the magnitude of the brake pedal torque request is greater than magnitude of the grade hold torque, electro-hydraulic brakes apply at the grade hold torque adding the difference between the brake pedal torque request and grade hold torque.
- [0063] When the magnitude of the brake pedal torque request is less than the magnitude of grade hold torque, electro-

hydraulic brakes apply at grade hold torque.

[0064] Rows 108 and 140 result in the engine off with a brake pedal torque request, and electro-hydraulic brakes applying at the grade hold torque.

[0065] The strategy continues with the electro-hydraulic brakes applying at the grade hold torque plus additional brake pedal torque request is added as follows.

[0066] When the magnitude of the brake pedal torque request is greater than the magnitude of grade hold torque, electro-hydraulic brakes apply at grade hold torque amount adding the difference between the brake pedal torque request and the grade hold torque.

[0067] When the magnitude of the brake pedal torque request is less than the magnitude of grade hold torque, the electro-hydraulic brakes apply at grade hold torque.

[0068] When the magnitude of the brake pedal torque request is less than X psi, where X is predetermined and calibratable pressure measured in psi, the hill holding strategy proceeds to the Figure 6 flowchart of the vehicle transition for when the engine is off.

[0069] Row 110 results in the engine on with an accelerator pedal torque request, and electro-hydraulic brakes applying at grade hold torque. The electro-hydraulic brakes applies at

the grade hold torque amount with the additional accelerator pedal torque request is added as follows.

[0070] When the magnitude of the accelerator pedal torque request is greater than the magnitude of grade hold torque, the hill holding strategy proceeds to the Figure 4

flowchart of the vehicle transition when the engine is on and operator desires to creep vehicle forward.

[0071] When the magnitude of the accelerator pedal torque request is less than magnitude of grade hold torque, the hill holding strategy proceeds to the Figure 7 flowchart of the vehicle transition for when the engine is on.

[0072] Row 112 results in engine off with an accelerator pedal torque request, and electro-hydraulic brakes applying at grade hold torque. Additional accelerator pedal torque request is added as follows.

[0073] When the magnitude of the accelerator pedal torque request is greater than the magnitude of grade hold torque, the hill holding strategy proceeds to the Figure 5 flowchart of the vehicle transition when the engine is off and the operator desires to creep the vehicle forward.

[0074] When the magnitude of the accelerator pedal torque request is less than the magnitude of grade hold torque, the hill holding strategy proceeds to the Figure 6 flowchart of

the vehicle transition for when the engine is off.

[0075] Row 114 results in the engine on and the electro-hydraulic brakes applying at grade hold torque. The hill holding strategy proceeds to the Figure 6 flowchart of the vehicle transition for when the engine is off.

[0076] Row 116 results in the engine off and the electro-hydraulic brakes applying at grade hold torque with the hill holding strategy waiting for a vehicle condition change.

[0077] Rows 118 and 150 result in the vehicle engine on in the two footer condition. The total torque request applies as follows.

[0078] When the total torque request is greater than zero, vehicle acceleration pedal applies at the total torque request amount. The hill holding strategy proceeds to the Figure 8 flowchart of the vehicle transition for when the engine is on with no electro-hydraulic brakes and the operator desires to creep the vehicle forward.

[0079] When the total torque request is less than zero, vehicle brake torque applies at the total torque request amount, the hill holding strategy proceeds to the Figure 11 flowchart of the vehicle transition for when the engine is on with no electro-hydraulic brakes.

[0080] When the total torque request equals zero, apply nothing.

The hill holding strategy proceeds to the Figure 11 flowchart of the vehicle transition for when the engine is on with no electro-hydraulic brakes.

[0081] Row 120 results in the engine off in a two footer condition. The total torque request applies according to the following.

[0082] When the total torque request is greater than zero, the vehicle acceleration applies at total torque request amount. The hill holding strategy proceeds to the Figure 9 flowchart of the vehicle transition for when the engine is off with no electro-hydraulic brakes and the operator desires to creep the vehicle forward.

[0083] When the total torque request is less than zero, the vehicle brake torque applies at total torque request amount. The hill holding strategy proceeds to the Figure 10 flowchart of the vehicle transition for when the engine is off with no electro-hydraulic brakes.

[0084] When the total torque request equals zero, apply nothing. The hill holding strategy proceeds to the Figure 10 flowchart of the vehicle transition for when the engine is off with no electro-hydraulic brakes.

[0085] Rows 122 and 154 result in engine on and applying the brake pedal torque request.

[0086] Rows 124 and 156 result in engine off and applying the brake pedal torque request. If the magnitude of brake pedal torque request is less than X psi, the hill holding strategy proceeds to the Figure 6 flowchart of the vehicle transition for when the engine is off.

[0087] Rows 126 and 158 results in engine on and applying the accelerator pedal torque request. If the vehicle speed is less than or equal to the creep speed then the hill holding strategy proceeds to the Figure 8 flowchart of the vehicle transition for when the engine is on with no electro-hydraulic brakes and the operator desires to creep the vehicle forward. If the vehicle speed is not less than the creep speed then the hill holding strategy proceeds to Figure 11 flowchart of the vehicle transition for when the engine is on with no electro-hydraulic brakes.

[0088] Rows 128 and 160 result in the engine off and applying the accelerator pedal torque request. The hill holding strategy proceeds to the Figure 9 flowchart of the vehicle transition for when the engine is off with no electro-hydraulic brakes and the operator desires to creep the vehicle forward.

[0089] Rows 130 and 162 results in the engine on and applying nothing.

[0090] Row 132 results in engine off and the hill holding strategy proceeds to the Figure 6 flowchart of the vehicle transition for when the engine is off.

[0091] Row 142 results in engine on with an accelerator pedal torque request and the electro-hydraulic brakes applying at the grade hold torque. The accelerator pedal torque request is added as follows.

[0092] When the magnitude of the accelerator pedal torque request is greater than or less than the magnitude of grade hold torque, the hill holding strategy proceeds to the Figure 4 flowchart of the vehicle transition when the engine is on and operator desires to creep vehicle forward.

[0093] Row 144 results in engine off and electro-hydraulic brakes applying at the grade hold torque plus the accelerator pedal torque request.

[0094] When the magnitude of the accelerator pedal torque request is greater than or less than the magnitude of grade hold torque, the hill holding strategy proceeds to the Figure 5 flowchart of vehicle transition when the engine is off and the operator desires to creep the vehicle forward.

[0095] Row 146 results in the engine on and the electro-hydraulic brakes applying at grade hold torque.

[0096] Row 148 results in engine off, electro-hydraulic brakes

applying at grade hold torque, the hill holding strategy proceeds to the Figure 6 flowchart of the vehicle transition for when the engine is off.

[0097] Row 152 results in engine off in the two footer condition. The total torque request applies according to the following.

[0098] When the total torque request is greater than or less than zero, vehicle acceleration applies at the total torque request amount. The hill holding strategy proceeds to the Figure 9 flowchart of the vehicle transition for when the engine is off with no electro-hydraulic brakes and the operator desires to creep the vehicle forward.

[0099] When the total torque request equals zero, apply nothing. The hill holding strategy proceeds to the Figure 9 flowchart of transition for when the engine is off with no electro-hydraulic brakes and the operator desires to creep the vehicle forward.

[0100] Row 164 results in the engine off and nothing applied. The hill holding strategy proceeds to the Figure 6 flowchart of the vehicle transition for when the engine is off.

[0101] Referring to Figure 4, flowchart of the vehicle transition when the engine is on and operator desires to creep vehi-

cle forward is provided.

[0102] In step 170, during each frame interval the following events occur. The forward clutch is applied. Next, a crankshaft torque sensor computes a traction torque at the crankshaft. The crankshaft torque can also be determined by sensing various engine factors such as speed, throttle angle, and fuel rate. Corrections to these input factors should be made if these factors were modified to perform additional functions that do not normally translate to drag on the drivetrain, for example some of the load of the engine may be diverted to supply the auxiliary load or charge or discharge the energy storage subsystem and may reflect as a higher throttle angle. The engagement factor is determined by sensing various clutch factors, such as pressure, to obtain the knowledge of what percentage of the torque applied to the clutch can be obtained at the clutch output. The gear ratio from the engine to the wheel is computed by knowledge of the present gear. The traction torque at the crankshaft computation, the engagement factor computation and the gear ratio from the engine to the wheel computation are a function of the driver accelerator pedal command and may be pre-programmed in an accelerator pedal map. The traction

torque at the crankshaft computation, the engagement factor computation and the gear ratio from the engine to the wheel computation compute the desired traction torque at each wheel.

[0103] Next in step 172, wheel traction torque desired is summed with the wheel brake torque desired to compute the total wheel torque delivered.

[0104] In decision step 174, the total wheel torque delivered is compared to zero.

[0105] If the total wheel torque delivered is greater than zero, then the flowchart continues to step 176. In step 176, the electro-hydraulic brakes torque is computed as the difference between the grade hold torque and the total wheel torque delivered.

[0106] If the total wheel torque delivered is less than or equal to zero, then the flowchart continues to decision step 178. In step 178, the magnitude of the brake pedal torque request is compared with the magnitude of the grade hold torque.

[0107] When the magnitude of the brake pedal torque request is greater than the magnitude of the grade hold torque, the flowchart proceeds to step 180 where wheel brake torque desired is calculated by summing the electro-hydraulic

brakes torque at grade hold torque and the brake pedal torque request minus the grade hold torque.

[0108] When the magnitude of the brake pedal torque request is less than or equal to the magnitude of the grade hold torque, the flowchart proceeds to step 182 where wheel brake torque desired is set to the electro-hydraulic brakes torque at grade hold torque.

[0109] Steps 176, 180 and 182 then proceed to step 184 where the total wheel torque delivered is computed as the difference between the wheel traction torque desired and the wheel brake torque desired.

[0110] Next in step 186 the electro-hydraulic brake torque is compared to zero. If the electro-hydraulic brake torque is equal to zero, then the hill holding strategy returns to the analysis in table of Figure 3. If the electro-hydraulic brake torque is not equal to zero the analysis returns to the top of the flowchart to step 170.

[0111] Referring to Figure 5, a flowchart of vehicle transition when the engine is off and the operator desires to creep the vehicle forward is provided. During each frame interval the powertrain control module starts the engine in step 200. Step 202 shows that the hill holding strategy proceeds to the Figure 4 flowchart of the vehicle transition

when the engine is on and the operator desires to creep the vehicle forward.

[0112] Referring to Figure 6, a flowchart of the vehicle transition for when the engine is off is provided. During each frame interval the powertrain control module starts the engine in step 204. Step 206 shows that the hill holding strategy proceeds to the Figure 7 flowchart of the vehicle transition for when the engine is on.

[0113] Referring to Figure 7, a flowchart of the vehicle transition for when the engine is on is provided. In step 210, the desired traction torque at each wheel is zero. The wheel brake torque desired is equal to the electro-hydraulic brakes torque. The flowchart continues to decision step 212 where the magnitude of the brake pedal torque request and the magnitude of the grade hold torque are compared to each other. The comparison is used to compute the amount of electro-hydraulic brake torque to be delivered at each wheel by the hydraulic system.

[0114] When the magnitude of the brake pedal torque request is greater than magnitude of grade hold torque, the flowchart goes to step 214. In step 214, the wheel brake torque desired equals electro-hydraulic brake torque at grade hold torque plus the difference between the brake

pedal torque request and the grade hold torque.

[0115] When the magnitude of the brake pedal torque request is less than or equal to the magnitude of grade hold torque, the flowchart goes to step 216. No additional friction brake torque is applied. The wheel brake torque desired equals electro-hydraulic brake torque at grade hold torque.

[0116] Steps 214 and 216 continue to step 218 where the total wheel torque delivered is computed by adding the wheel traction torque desired with the wheel brake torque desired.

[0117] The flowchart continues with decision step 220 where the electro-hydraulic brake torque is compared to zero. If the electro-hydraulic brake torque is equal to zero the flowchart goes back to the initial analysis in FIG. 3 table as shown in step 222. If the electro-hydraulic brake torque is not equal to zero the system returns to step 210 of the Figure 7 flowchart.

[0118] Referring to Figure 8 flowchart of the vehicle transition when the engine is on with no electro-hydraulic brakes and operator desires to creep vehicle forward.

[0119] In step 230, during each frame interval the following events occur. The forward clutch applies. Next, a

crankshaft torque sensor, or other sensing methods enable the computation of the traction torque at the crankshaft. Clutch sensors enable computation of the engagement factor. Knowledge of present gear enables computation of the gear ratio from the engine to the wheel. The traction torque at the crankshaft computation, the engagement factor computation and the gear ratio from the engine to the wheel computation are a function of the accelerator pedal command and may be preprogrammed in an accelerator pedal map. The traction torque at the crankshaft computation, the engagement factor computation and the gear ratio from the engine to the wheel computation are used to compute the desired traction torque at each wheel.

[0120] Next in step 232, wheel traction torque desired is summed with the wheel brake torque desire to compute the total wheel torque delivered.

[0121] Next in step 234, the clutch is determined to be fully engaged or not. If the clutch is determined to be fully engaged, then the flowchart strategy returns to the analysis in table 90 of Figure 3. If the electro-hydraulic brake torque is not equal to zero the analysis returns to step 230 of the flowchart of the vehicle transition when the en-

gine is on with no electro hydraulic brakes and operator desires to creep vehicle forward.

[0122] Referring to Figure 9, a flowchart of transition for when the engine is off with no electro-hydraulic brakes and the operator desires to creep the vehicle forward is provided.

[0123] In step 240, the powertrain control module turns the engine on. The flowchart continues to step 242, where the hill holding strategy proceeds to the Figure 8 flowchart of the vehicle transition when the engine is on with no electro-hydraulic brakes and the operator desires to creep the vehicle forward.

[0124] Figure 10 flowchart of transition for when the engine is off with no electro-hydraulic brakes. In step 244, the powertrain control module turns the engine on. The flowchart continues to step 246, where the hill holding strategy proceeds to the Figure 11 flowchart of the vehicle transition when the engine is on with no electro-hydraulic brakes.

[0125] Referring to Figure 11, a flowchart of transition when the engine is on with no electro-hydraulic brakes is provided.

[0126] In step 260, the wheel traction torque desired at each wheel is zero.

[0127] In step 262, the amount of electro-hydraulic brake torque

to be delivered at each wheel by the hydraulic system is zero and wheel brake torque desired equals brake pedal torque request.

[0128] In step 264, the total wheel torque delivered equals wheel traction torque desired plus the wheel brake torque desired.

[0129] The flowchart continues with decision step 266 where the decision on clutch engagement is made. If the clutch is engaged the flowchart goes back to the initial analysis in Figure 3 table 90. If the clutch is not fully engaged the flowchart proceeds to step 260 of the Figure 11 flowchart.

[0130] While the best mode for carrying out the invention has been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention as defined by the following claims.